Note on Horizontal Receivers and Transmitters in Wireless Telegraphy.

By Prof. H. M. Macdonald, F.R.S.

(Registered July 18, having been received by the Secretary at Cambridge, May 12,—Read November 19, 1908.)

In a communication published in the 'Proceedings,'* Mr. Marconi has given the results observed when a straight horizontal conductor is substituted for the usual vertical conductor employed as a transmitter or receiver at a wireless telegraph station. The object of the following note is to consider the theory of such an arrangement, or at any rate one aspect of it. The receiver, as being the more important, will be considered first.

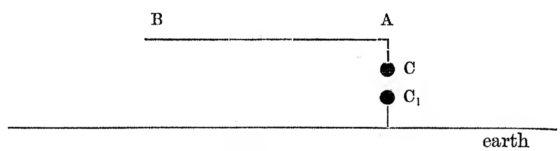

Fig. 1.

Let AB (fig. 1) represent the horizontal receiver, consisting of a straight conductor having the end A connected to a spark-gap CC_1 or other wave-detector. The electric oscillations in AB can be represented by a distribution of Hertzian oscillators along AB, and, if L denotes the current strength at any point of AB, it must satisfy the conditions $L = 0$ at B, the free end, and $dL/ds = 0$ at A, since the electric force perpendicular to AB at A must vanish. If the distance of AB from the earth is not too small, the effect of the oscillations belonging to the image in the earth of AB on those in AB may be neglected, the radiation from the free end B will be approximately symmetrical with respect to AB, and the oscillations in AB are then approximately the same as if BA formed part of a semi-infinite straight conductor in which a system of oscillations is being maintained, B being the free end and A the first node from the free end; the wave-length of these oscillations is very approximately five times the length of AB,† and therefore the receiver is of maximum efficiency when its length is one-fifth of the length of the transmitted wave, a result observed by Marconi.‡ When the distance of AB from the earth is so small that the effect of the oscillations in the image of AB in the earth on the oscillations in AB is not negligible, the radiation

* Vol. 77, A, March, 1906.

† Macdonald, 'Electric Waves,' 1902, Ch. X.

‡ 'Roy. Soc. Proc., A, vol. 77, p. 421.

from the free end B will not be symmetrical with respect to AB, but may be taken as being approximately symmetrical with respect to some line through B making an angle with BA; the wave-length of the oscillations in AB is therefore equal to the wave-length of the oscillations in a bent conductor joining AB; that is greater than five times the length of AB, and, therefore, in this case the receiving conductor has its maximum efficiency when its length is somewhat less than one-fifth of the length of the transmitted wave, a result also observed by Marconi.* To examine the effect of the orientation of the receiver, consider a straight conductor BAB′ twice the length of AB (fig. 2) and its image $B_1A_1B_1'$ in the horizontal plane, A and A_1 being their middle points respectively.

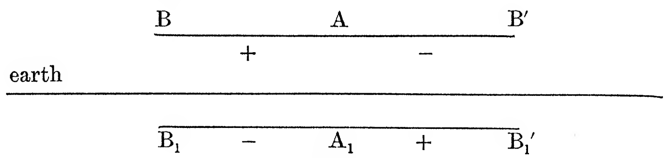

Fig. 2.

When electric oscillations are being maintained in BB′ with the corresponding set in B_1B_1', A and A_1 are nodes, hence, if a wave-detector is placed in AA_1, no effect will be observed in it due to its own oscillations, and therefore the potential difference at CC_1, due to the forced oscillations in the receiver when the receiver AB is in the position fig. 1 is equal and opposite at any instant to the potential difference at CC_1 when the receiver is in the position which results from turning it through two right-angles round CC_1. Now, the total effect at CC_1 is made up of two parts, one due to the direct action of the advancing waves, the other due to the oscillations in the receiver. If in fig. 1 the advancing waves be supposed to be travelling from left to right, the oscillations in the receiver may be regarded as the resultant of two sets of progressive waves, one travelling from B to A and the other from A to B; and, since the oscillations in the receiver are maintained by the advancing waves, the set of progressive waves in the receiver travelling from B to A must be in the same phase as the advancing waves at A. Further, since the electric force perpendicular to AB at A vanishes, the electric distribution on AC has at any instant the opposite sign to that on AB, and therefore the potential difference at CC_1 due to the oscillations in the receiver is at each instant in the opposite phase to the potential difference due to the direct action of the advancing waves. Hence, if α denote the maximum potential difference at CC_1 due to the direct action of the advancing waves, and β the maximum potential difference due to the oscillations in the

* *Loc. cit.*

receiver, the potential difference at CC_1 at any instant is $(\alpha-\beta)\cos pt$. When AB is turned through two right-angles round CC_1, the advancing waves still travelling from left to right, the set of progressive waves in the receiver travelling from B to A must be in the opposite phase to the advancing waves at A, since the oscillations in the receiver are, as before, maintained by the advancing waves, and therefore the potential difference at CC_1 due to the oscillations in the receiver is in this case in the same phase as that due to the direct action of the advancing waves, and is at any instant $(\alpha+\beta)\cos pt$. Hence the total effect at CC_1 is greater when the free end B is pointing directly away from the transmitter than when it is pointing directly towards it. In the above the receiver AB has been assumed to be placed perpendicularly to the wave fronts of the advancing waves. When, in fig. 2, BB′ is in the plane of the wave fronts of the advancing waves, no oscillations will be set up in BB′; and, therefore, when BB′ makes an angle θ with the direction of the advancing waves, the amplitude of the oscillations in BB′ lies between zero and the value corresponding to $\theta = 0$. Hence, when the receiver AB makes an angle θ with the direction in which the transmitted waves are advancing, the potential difference at CC_1 is $\alpha\cos pt + f(\theta)\cos(pt+\epsilon)$, where $\beta > f(\theta) > 0$, and ϵ depends on θ. If, then, a curve be drawn to represent the potential difference in terms of the orientation of the receiver, it will be of the form of the figure 8, with unequal loops, the larger loop being further from the transmitter, its greatest radius being $\alpha+\beta$.

When the horizontal conductor is used as a transmitter, its effect is made up of two sets of oscillations, one from the oscillations in the horizontal conductor emanating from the free end, the other from the vertical spark-gap. At a distance the effect of the first set is the same as that of a horizontal Hertzian oscillator with its image in the horizontal; hence, choosing axes of reference such that z is vertical and x is measured horizontally in the direction of AB, the vertical electric force at a distance due to this set is

$$B\frac{\partial^2}{\partial x\partial z}\cdot\frac{\partial}{\partial z}\frac{\sin\kappa(r-Vt)}{r}.$$

The vertical electric force due to the second set is

$$A\left(\frac{\partial^2}{\partial z^2}+\kappa^2\right)\frac{\sin\kappa(r-Vt)}{r};$$

hence, retaining only the more important terms, the vertical electric force at the surface at a distance is

$$\left(A-B\frac{x}{r^2}\right)\frac{\kappa^2}{r}\sin\kappa(r-Vt)+A\frac{\kappa}{r^2}\cos\kappa(r-Vt),$$

where A and B have the same sign, as the waves proceeding from the free end are at the free end in approximately the opposite phase from those

proceeding from CC_1. Hence the square of the amplitude of the vertical force at a distance is

$$(A - \frac{B}{r} \cos \theta)^2 \frac{\kappa^2}{r^2} + A^2 \frac{\kappa^2}{r^4},$$

where θ is the angle the direction of the receiver makes with AB, and for a given value of r this gives a figure 8 curve, with unequal loops to represent the intensity of the transmitted waves.

[*Added August* 31.—The essential feature of the various systems of directed wireless telegraphy is the interference of two sets of waves differing in phase and proceeding from sources at a distance apart. Braun's* arrangement consists of three vertical antennæ, each 20 metres high, placed at the corners of an equilateral triangle whose side is 30 metres. The waves proceeding from one of these differs in phase by $\pi/2$ from the waves proceeding from the other two. For the best effect the perpendicular of the triangle is a quarter of a wave-length, as then the waves proceeding in one direction are in the same phase, while those proceeding in the opposite direction are in opposite phases. For this $\lambda/4 = 30 \cos \pi/6$, that is $\lambda = 103$, or approximately five times the height of the antenna, agreeing with theory.

Artom's† arrangement consists of two equal antennæ, each inclined at an angle of 45° to the horizontal, the oscillations in them differing in phase by $\pi/2$. The antennæ are bent through an angle of 90° at the ends above the horizontal, and led to conductors; the waves that interfere are those radiated from the bends, and the wave-length for the greatest effect will be greater than five times the length of the straight part of an antenna, the radiation from the bend not being symmetrical with respect to the antenna. For complete interference, that is, with the waves in one direction in the same phase, and the waves in the other direction in opposite phases, the distance between the two bends is a quarter of a wave-length; hence, if a is the length of the straight part of each of them, $\lambda/4 = 2a \cos \pi/4$, that is $\lambda = 5{\cdot}6\,a$. In Marconi's‡ arrangement the two sources are the spark-gap and the free end of the horizontal conductor, whose distance apart is approximately one-fifth of a wave-length, while the oscillations differ in phase approximately $\pi/2$, the waves at the bend differing in phase by π. It should be observed that in Braun's arrangement and Artom's arrangement the amplitudes of the two component sets of waves are for all distances in the same constant ratio, while in Marconi's arrangement the amplitudes are in a ratio which varies as the distance.]

* 'Jahrbuch Drahtl. Tele.,' vol. 1.

† 'Accad. dei Lincei,' Roma, vol. 15, p. 692, 1906.

‡ *Loc. cit.*